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自然噪声和白噪声对凹耳蛙高频听觉反应
特征影响的胞外电生理学研究

Extracellular study of effect of natural and white noises on
high-frequency auditory response characteristics of the
Concave-eared torrent frog, *Odorrana tormotus*.

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自然噪声和白噪声对凹耳蛙高频听觉反应特征影响的电生理学研究
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摘要

通讯是动物间建立一切社会关系的基础，声通讯是通讯的一种形式，对动物的生存至关重要。声信号传播的效率取决于发声者发声强度、传播介质的物理性质、声音接受者的敏感性和环境噪声强度等一系列因素。环境中高强度的噪音与动物鸣声频率、振幅和鸣唱时间会发生冲突，噪音对鸣声的影响主要是降低声信号的传播距离、干扰声信号内容，进而导致声音传播效率下降，信号保真性降低。鸟类、两栖类等主要依靠鸣声通讯，鸣声传播效率下降进而会影响动物个体间识别、配偶关系、领域防卫、种群密度、母子行为协调等。在大自然中噪声可谓无处不在。

研究表明，噪声会削弱个体间的信号交流，因此动物（哺乳类、鸟类、两栖类）产生了各式各样适应策略应对环境噪声的。作为信号发出者，包括长期适应和短期适应。长期适应如提高叫声主频、采用视觉信号等，短期适应包括调整信号幅度、时长、重复度、频谱特点和时间选择等。对于接受者，可以通过改变与信号源和噪声源的相对位置、频谱感受性、音调处理、幅度和时长依赖性以及特征感受器等来提高感受性。

近年的研究已发现栖息在安徽省黄山市桃花溪周边的雄凹耳蛙(*Odorrana tormota*)可以发出并检测超声，其听觉上限分别为35 kHz (87 dB SPL)，说明凹耳蛙可以进行高频甚至超声通讯。凹耳蛙的繁殖时期在每年4至6月间，此时恰逢黄山桃花溪的雨水较多，环境噪声甚至能达到90 dB SPL以上。为了研究这些自然噪声对凹耳蛙的听觉反应特征作用，并与人造白噪声的作用相比较，我们从电生理角度研究了三种噪声水平五种噪声条件（37dB SPL背景噪声、65dB SPL自然噪声和白噪声、85 dB SPL自然噪声和白噪声）对凹耳蛙听觉反应特征的影响。在隔音室内，以雄凹耳蛙为研究对象，给予5 kHz—21 kHz的纯音刺激，细胞外记录中脑半圆体（torus semicircularis, TS）区神经元群的听觉诱发近场电位（auditory evoked near-field potentials, AENFPs）和单单位神经元放电反应（single unit spike）。比较五种噪声条件下各个频率的三个重要听觉反应特征参数：相对幅度、潜伏期、听觉诱发近场电位及单单位神经元反应特征频率阈值。

实验结果显示：雄性凹耳蛙的特征频率主要分布在7—9kHz、11—15kHz、17—19kHz 三个区段，无论特征频率为低频组、中频组或高频组，相比于37dB SPL背景噪声组，中等强度（65dB SPL自然噪声和白噪声）噪音对雄凹耳蛙AENFPs 的幅度、潜伏期和特征频率的阈值几乎无影响。在高噪声（85 dB SPL自然噪声和白噪声）中，潜伏期普遍延长，相对幅度明显降低，特征频率的阈值明显上升,说明凹耳蛙中脑神经元编码听觉信息易受到高强度噪声的影响。单单位神经元特征频率的阈值结果显示与AENFPs结果相似。

结论：1) 雄性凹耳蛙的特征频率主要分布在 7—9kHz、11—15kHz、17—19kHz 三个区段；2)中等强度（65 dB SPL）噪声对凹耳蛙的听觉反应特征参数无明显影响；3）高强度噪声（85 dB SPL）对凹耳蛙的听觉反应特征有明显的抑制作用；4）同等强度的白噪声的压抑作用比自然噪声更为显著，我们推测这可能与自然噪声和白噪声的频谱有关。

关键词：雄凹耳蛙自然噪声白噪声听觉诱发近场电位相对幅度

潜伏期特征频率阈值单单位神经元反应

Abstract

Communication is the foundation upon which all social relationships between animals are built. Acoustic communication is one form of communication, which is critique to animals. The efficiency of acoustic communication mainly depends on the power generated by the senders, the physical properties of the environment through which signals propagate, the auditory sensitivity of the intended receivers as well as the level of the background noise. For the animals living in the habitats with high level of ambient noise, their vocalizations could be overlapped with the frequency, amplitude, and temporal characters of the noise. While traveling through the environment, acoustic signals are subjected to degradation, and signal propagation is especially limited by frequency - dependent attenuation, making the spread efficiency of the animals acoustic signals decreased. Birds and toads mainly rely on their songs for communication, so the spread efficiency of their acoustic signal will impact them in neighbour—stranger discrimination, mate selection, territory defence, population density, community structure, and so on. Ambient noise is ubiquitous in natural habitats.

Studies have shown masking noise impairs the exchange of information between individuals by acoustic signals, thus animals have evolved various adaptations to cope with interference from background noise. As senders, they adjust signal features through long - term adaptations and short-term adaptations. Long - term adaptations refers to acoustic signals was shaped to stand out against the sounds of the background to minimize masking by background noise and the use of two communication channels at the same time improves the probability of signal detection. In order to get their messages through the noise, sound-producing animals may adjust the characteristics of their acoustic signals, which include regulation of signal amplitude, duration, redundancy, pitch to counteract interference from environmental noise. In addition to through changing position in the habitat relative to signal and

noise sources to improve signal-to-noise ratio, receivers also adjust spectral sensitivity, amplitude and duration dependence, feature detectors to improve the ability to hear signals in a rather noisy environment.

In recent years, it has been discovered that *Odorrana tormota*, a frog living in torrent streams in Mt. Huangshan could detect and respond to high-frequency signals up to ultrasound. Field playback experiment and recordings from TS indicated that this frog evolved high-frequency acoustic communication (≥ 20 kHz) in signal exchanges with upper limit of 35 kHz (87 dB SPL). During breeding season, which is between April and June, the ambient noise could be up to >90 dB SPL due to the rainy weather. It is largely unknown how noise affects the hearing sensitivity of *O. tormota*.

In order to study how moderate and high level of noise affect *O. tormota* hearing ability from electrophysiology perspective, we conducted measurements of the auditory evoked near-field potentials (AENFPs) and the threshold of characteristic frequency at 37dB SPL background noise, 65dB SPL natural noise and 65dB SPL white noise (moderate level), 85dB SPL natural noise and 85dB SPL white noise (high level).

We found that this frog exhibits three most sensitive range of frequencies: 7-9 kHz, 11-15 kHz, and 17-19 kHz. Compared with 37dB SPL background noise, relative amplitude and the threshold of characteristic frequency was affected little by moderate level of noise, The relative amplitude decrease and the threshold at CFshif indicate that neural coding by auditory midbrain neurons in the *Amolops tormotus* is subject to noise fluctuation. The effects of five conditions of noises in single unit studies were similar to those in AENFPs.

Conclusions: 1) We found that characteristic frequency mainly distributed in 7-9 kHz, 11-15 kHz and 17-19kHz; 2) Compared with 37dB SPL background noise, relative amplitude, latency and the threshold of characteristic frequency was affected lightly by moderate level of noise; 3) In contrast, significant difference exists between background noise and high level of noise in relative amplitude and the threshold of characteristic frequency at all tested frequencies; 4) Compare with natural noise,

relative amplitude and the thresholds of characteristic frequency were impair much by white noise.

Keywords: Natural noise; White noise; Auditory evoked near-field potential; Relative amplitude; Latencies; Threshold of characteristic frequency; Single unit

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第一章相关文献综述

1.1 噪声简介

通讯是一切生物之间建立关系的基础,绝大多数动物依赖生通讯检测、区别和定位配偶^[1, 2]。一个完整的声通讯的过程包括发声者由振动发出声音,以波的形式在一定的介质(如气体、液体、固体)中传播,最后被接受者接收。声信号传播的效率取决于发声者发声强度、传播介质的物理性质、声音接受者的敏感性和环境噪声强度等一系列因素^[1-4]。声音的大小由振幅决定,音调的高低由频率决定。在通常情况下,绝大多数感受形态下的信号的传递都被背景噪声严重抑制,噪声是降低一个接受者检测一个信号或者区别两种信号能力的一个重要因素^[3-7]。关于噪声的定义有很多,在生物声通讯领域目前比较公认的定义是指对声音的传播有衰减作用、对听觉和健康造成损害的声音。噪声按来源可以分为外部噪声和内部噪声。内部噪声方面的报道较为少见,是指接受者感受通路中产生的噪声。外部噪声可以分为自然噪声和非自然噪声,以及人为噪声。自然噪声诸如鸟类的鸣唱、蚕鸣、无尾目的聚集等,非自然噪声包括空气流动、下雨声和水流声(激流和瀑布)^[1]。自第二次工业革命以来,城市人口和机动车的急剧增加使人为噪音水平不断升高,人为噪声对动物声通讯的影响也引起了特别的关注,在蛙类^[8-13]、鸟类^[14-21]、鲸^[22-25]和其他哺乳类动物^[26-28]中已经有大量的研究。噪声按频率分布来分可以分为粉红噪声、褐色噪声和白噪声。粉红噪音的频谱主要分布在中低频段,是自然界最常见的噪声。白噪声是指功率谱密度在整个频域内均匀分布的噪声,也就是所有频率具有相同能量密度的随机噪声,简单的来说,也就是白噪声在各个频率的声强相等。

尽管我们容易忽视噪声带来的问题,但是在自然界,噪声可谓无处不在,环境噪声尤其丰富。

1.2 噪声对动物声通讯的影响以及动物的适应策略

噪声对主要依靠声音进行通讯的类群影响比较严重。在高噪声环境中生存的动物,发出的声信号会与噪声的频率、振幅和时间等重叠,使动物声信号的传播效率降低。对于主要靠声通讯的动物来说,声信号传播效率下降会影响动物配偶关系^[29-32]、领域防卫^[1, 14, 33-37]、捕食^[38-44]和反捕食^[38, 43, 45-47]等。

1.2.1 噪声对动物声通讯的影响

众多的文献资料表明噪声对动物声通讯具有限制和干扰作用。噪声对鸟类的影响方面的文献报道非常多,对于鸟类而言,其主要通过鸣声来进行通讯,从而完成吸引配偶、领域防卫、预警危险、捕食和求救、躲避天敌、母子行为协调等一系列重要的生命活动。噪音干扰鸟类寻找觅食适合区和追赶猎物并辨别天敌位置的能力,使鸟类的捕食效率和生存能力大大下降。如图1.1,大鼠耳蝠(*Myotis myotis*)靠发出“沙沙沙”的声音来寻找食物,在声音密闭室内的耳蝠一般只在噪音源对面的空间内捕食活动,它们进入到噪音区的飞行时间、次数、捕食效率就大大降低(Schaub et al., 2008)。生活在城市中的苍头燕雀(*Fringilla coelebs*)是猫科动物和一些食肉类猛禽潜在的捕食对象,与安静地区的同种鸟类相比,高强度的人为噪音严重干扰了苍头燕雀通过声音辨别天敌的能力,它必须提高视觉探查频率,导致侦查天敌的耗时延长,觅食耗时缩短,觅食效率会降低,存活指数降低^[48, 49]。噪声对哺乳动物的影响研究比较多的是小鼠,主要集中在研究噪声对其生长发育、听器损伤和脑发育影响等方面,并且已有大量文献证明了高强度噪声声不仅可产生耳蜗组织结构损伤,甚至会引起听阈变化、听力损失,从而影响小鼠中枢神经系统的功能和脑发育等^[50, 51]。噪声对节肢动物行为学影响的研究报道也较多,在宽频带噪声中,雌性短翅草螽(*Conocephalus brevipennis*)识别雄性的能力有所下降^[52, 53]。噪声对两栖类听觉感受性影响的研究比较多,但是目前仅集中于行为学方面:一种雌性新热带蛙在信噪比SNR >25 dB的自然合唱噪声中,更偏好较低频率的雄蛙叫声;当信噪比SNR为6-9 dB(中等强度)时,则不能从识别雄性;当信噪比SNR为3 dB(高强度)时,则雌性热带蛙偏好接近种群典型频率的雄蛙叫声^[32]。Narins等从电生理方面证明了外在的噪声破坏了蛙的听觉神经元的锁时效应,影响了反应时间和节律^[54]。

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